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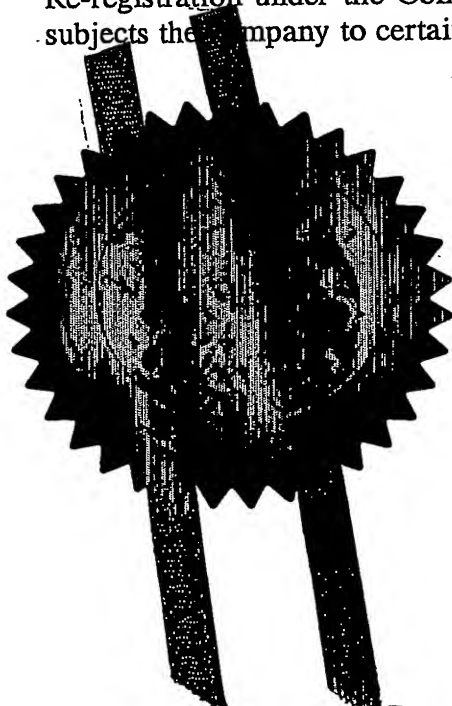
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Dated

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# Request for grant of a patent

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22 MAY 2004

1. Your reference

1418/C

2. Patent application number

(The Patent Office will fill in this part)

0411522.6

24MAY04 E898303-4 D02819  
P01/7700 0.00-0411522.6 CHEQUE

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Unova UK Ltd  
26 Temple Street  
Aylesbury  
Buckinghamshire  
HP20 2RQ

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

England

08757965001

4. Title of the invention

Improved grinding wheel spindle

5. Name of your agent (if you have one)

Keith W Nash & Co

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

90-92 Regent Street  
Cambridge  
CB2 1DP

Patents ADP number (if you know it)

1206001 ✓

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)

Date of filing  
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

Yes

- a) any applicant named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
- See note (d))

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Continuation sheets of this form

Description *8 9 ✓*

Claim(s) *W~*

Abstract

Drawing(s) *3 + 3 ✓*

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (*Patents Form 7/77*)

Request for preliminary examination and search (*Patents Form 9/77*)

Request for substantive examination (*Patents Form 10/77*)

Any other documents  
(*please specify*)

11.

I/We request the grant of a patent on the basis of this application.

Signature *[Signature]*

Date 21/05/04

Keith W Nash & Co., Agents

12. Name and daytime telephone number of person to contact in the United Kingdom

Keith Nash 01223 355477

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C1418/C

Title: Improved grinding wheel spindle

### Invention

This invention concerns grinding wheel spindles

### Background

Automotive engine designers have realised that a better performing engine can be achieved by modification of the camshaft lift profile. Thus the profile of that part of the cam which controls the actual opening and closing of the valve, is modified from a conventional flat or convex shape so as to possess a concave region. A camshaft of this type is known as having a re-entrant profile.

This type of profile manifests itself on the cam lobe as a depression in the lift/closure flank of the cam, which can only be produced with a grinding wheel whose external radius is the same as, or more preferably smaller than, the minimum radius of the cam form. Non re-entrant cam profiles can of course be ground with wheels of unlimited radius.

A number of issues are faced when designing grinding wheel spindles for this task;

1. Due to the small grinding wheel diameter, the spindle speed has to be proportionally higher to maintain a satisfactory wheel surface speed.
2. The grinding wheel must be capable of reaching the base circle diameter of each cam lobe, and in particular a cam lobe at the end of a camshaft remote from the spindle housing, while allowing the tips of other lobes to rotate clear of the spindle body is

situated parallel to the camshaft. Therefore the spindle shaft is restricted in diameter to allow this clearance.

It is therefore necessary for the rotating shaft to be long, to be of small diameter and to be able to run at high rotational speeds.

Spindle design considerations dictate that the first resonant bending mode for a rotating shaft should reside beyond the maximum spindle rotating frequency. This arises from the observation that as spindle speed approaches its resonant frequency, resonance can be excited and spindle performance will be affected, often to the point of failure.

Hitherto this problem has usually been avoided by arranging that the resonant frequency of the spindle is as high as possible. Conventionally this has been achieved by using shafts which are short in axial length and have as large a diameter as is practical.

This is the very antithesis of the requirements for a grinding wheel spindle which is adapted to grind re-entrant cam profiles.

#### Summary of Invention

According to one aspect of the present invention a spindle for a grinding wheel which is to grind re-entrant cams includes three shaft bearings so as to increase the shaft stiffness and increase its resistance to bending.

Conventionally the spindle shaft is a continuation of an electric motor shaft, on which a rotor is mounted, and the shaft is driven by the magnetic field acting on the rotor and produced by a stator within which the rotor rotates, and the shaft has been supported in two axially spaced apart bearings, typically, with one bearing positioned close to the grinding wheel, and a second bearing placed either before or after the rotor. By employing three bearings the shaft can be supported in bearings at opposite ends of the shaft and at a mid-position.

In particular the shaft is constructed so as to have at least two different diameters, and that part of the shaft which is formed integrally with the rotor has a greater diameter than does that part of the shaft which extends axially externally from one end of the electric motor drive, (the external part of the shaft) and which has the grinding wheel mounted at its far (outboard) end.

Preferably one bearing is located at the outboard (wheel) end of the shaft just before the wheel, the mid-position bearing is located at the inboard end of the external part of the shaft (just before the rotor), and the third bearing is located at the other (rear) end of the rotor.

Preferably the grinding wheel is mounted on the shaft where it extends beyond the said one bearing.

Preferably the spindle is encased within a rigid hollow body which latter is rigidly joined or integrally formed with a rigid housing containing the stator of the motor, and the non-rotating element of each of the three bearings is secured within either the spindle body or the motor housing

Typically the axial length of the rotor bearing part of the shaft will be much shorter than the main part of the shaft, and the bending resonance of the longer main part is kept above the critical spindle rotational frequency by the stiffness and the support of the shorter, inboard part of the shaft which includes the rotor, and which is situated between the mid-position bearing and the rear end bearing.

Preferably each of the bearings is a hydrostatic bearing so as to ensure long life and provide high impact load tolerance and good vibration damping, so as to produce good grind performance and high surface finish of ground components.

As already stated, traditionally a grinding wheel spindle shaft has only been supported by two bearings and therefore bearing alignment has not been an issue. However, if three bearings are to be employed, alignment of the three bearings is very important. Where hydrostatic bearings are involved this is a very real problem since typically hydrostatic bearings have radial clearances (and therefore an oil film thickness) of the order of 25 microns, and if vibration is not to be introduced due to misalignment, any adjustment mechanism to achieve alignment needs to be capable of microscopic movements much smaller than the hydrostatic film thickness.

According therefore to another aspect of the present invention, during assembly the internal bores of two of the bearings are initially aligned and then the third bearing is adjusted radially to bring all three bores into alignment.

However, alignment of the bearings is not restricted to ensuring their alignment during assembly, since at the high speeds required of grinding processes using small wheels, considerable heat can be generated within the bearings, and the spindle can also become heated by heat from the grinding wheel at one end and the electric motor (when under load) at the other end. This can result in variations in the spindle temperature in a non-axisymmetrical manner, resulting in bending due to differential thermal expansion taking place. This can result in misalignment of the spindle shaft and the bearings. This is particularly the case if the differential thermal expansion is occurring in different radial regions of the spindle structure.

According therefore to another aspect of the invention a symmetrical design of housing is employed for the motor and a water cooling jacket is provided in which water is forced to follow a helical path around the motor, so as to avoid cooling one side of the motor more than another, which can occur if a direct path is available between inlet and outlet of a cooling water jacket.

According to a further aspect of the invention wherever possible the spindle is constructed to be axisymmetrical, so that any heat generated within the bearings dissipates radially into

the surrounding material in a uniform manner. In this way the spindle housing will tend to warm up and cool down uniformly, and therefore expand and contract uniformly.

In use, the oil in a hydrostatic bearing becomes heated and rises in temperature. The oil is circulated through the bearing by a pump which draws oil from a reservoir to which the oil returns from the bearing. However, within the spindle housing, the oil which has left a bearing will tend to accumulate in the lower part of the housing (previously referred to) before it returns to the reservoir. Since this is oil which has just been heated in the bearing and is at its hottest, the lower region of the spindle housing can become heated to a higher temperature than the upper region of the housing. This can result in bending and distortion of the spindle housing which again can cause misalignment of the bearings and can impart a strain on the spindle shaft.

According therefore to a further aspect of the invention, in order to overcome the potential for distortion due to a hot zone being created in the lower regions of the spindle housing, a separate oil collection box is provided which is mounted to the spindle housing in such a manner that it will not impart a strain on the spindle shaft and preferably a thermal barrier is provided between the oil collection box and the spindle housing to reduce the transfer of heat from the hot oil in the box to the housing.

The invention will now be described by way of example with reference to the accompanying drawings in which:-

Figs 1 (a) and (b) illustrate how conventional profile and re-entrant profile cam can be ground,

Fig 2 illustrates how the spindle shaft diameter is restricted where the workpiece contains regions of differing radial extent as in the case of cams along an engine camshaft,

Fig 3 illustrates the axial space required for camshaft clearance,



Fig 4 illustrates diagrammatically how the spindle shaft can be supported by three bearings (instead of the conventional two),

Fig 5 illustrates diagrammatically how cooling fluid can be made to flow in a helical path around the spindle drive motor and,

Fig 6 shows how oil leaves a hydrostatic bearing.

As shown in Fig 1 (a) a conventional cam profile 10 which contains no re-entrant (concave curvature) region can be ground using a relatively large diameter grinding wheel 12. Where (as is usual) the wheel diameter is considerably greater than the diameter of the spindle and drive motor, the wheel can be positioned anywhere along the length of a camshaft workpiece without there being any risk that the spindle or motor will be engaged by any part of a rotating cam.

The situation is rather different when grinding re-entrant cam profiles such as shown in Fig 1 (b). Here the diameter of the grinding wheel 14 must be such that it can enter the region of "concave" curvature 16,18 around the profile 20, to grind each curved face without simultaneously grinding away adjoining larger radiused regions of the profile - as would occur if a larger diameter wheel (such as 12 in Fig 1 (a)) were to be used.

It has been proposed to use two grinding wheels and to grind re-entrant profiles such as 20, by first using a larger wheel such as in Fig 1 (a) to form a non re-entrant profile (or partly re-entrant to the extent that the diameter of the larger wheel will allow) and then to use a smaller wheel such as shown in Fig 1(b) to grind the re-entrant (concave) regions 16, 18. However, this two stage process increases grinding time.

Instead it has been proposed to use a single small diameter grinding wheel to perform at least the whole of the final grinding of re-entrant cams of an engine camshaft. However, this presents problems where there is a requirement for significantly smaller radius re-entrancing cams, and correspondingly smaller diameter wheels have to be employed. The

problem is demonstrated in Fig 2, which shows how the cams do not all protrude in the one radial direction from the camshaft, and the base circle region 22 of one cam 23 can coincide with the tip 24 of another cam 25, albeit axially distant from the former. The wheel diameter is denoted by 26 and the wheel is shown mounted on a shaft 27. The diameter of the wheel is such as to be capable of grinding the desired radius of curvature of the re-entrancy in the cam lobe.

In order to follow the cam lobe surface as the camshaft rotates about its axis 28, the wheel axis 30 has to move towards and away from the camshaft axis 28 during the grinding process, typically under computer control in manner known per se. This is achieved by moving the wheelhead 32 in the forward and backward directions indicated by arrow 34. However, as will be seen with particular reference to Fig 3, when the wheelhead 32 has moved to the right in Fig 2, so that the wheel 26 can grind the base circle region 22 of a cam 23, it is important that the spindle housing 36 surrounding the shaft 27 does not interfere with the tips of other cams such as tip 24 of cam 25 in Fig 2. This puts a constraint on the cross section size of the spindle housing 36.

Fig 3 shows the drive motor housing 38 which is larger in diameter than the spindle housing 36. This demonstrates that the spindle needs to extend axially to the left of the drive motor housing 38 by at least the axial length of the camshaft 40, so that the housing 38 will not interfere with the rotating cams. The spindle shaft 27 therefore has to be much longer than the case where the wheel diameter is significantly greater than that of the spindle housing 36 and drive motor housing 38. (It will be appreciated that where a larger diameter wheel is involved the shaft 27 need only protrude from the drive motor housing 38 by a sufficient length to allow the wheel to be mounted thereon). Since the spindle shaft 27 now needs to be as long as the workpiece 40, and the spindle and shaft are constrained in diameter for the reasons given above, the invention proposes the use of the third bearing as shown in Fig 4, so as to stiffen the shaft.

In Fig 4 the rotor 40 can be seen mounted on, or formed integrally with, part of the spindle shaft 27 and the small diameter grinding wheel 26 is shown mounted on the

extreme left hand (outboard) end of the shaft. The latter is supported by three hydrostatic bearings 44,46,48. The bearings 44 and 46 are located at opposite ends of the rotor 40 and the outer race of bearing 44 is mounted within the right hand end of the rigid cylindrical housing 38 (not shown in Fig 4) which houses the stator (not shown) of the motor.

The bearing 48 is located adjacent to the grinding wheel while bearings 46 and 48 are positioned either side of the rotor 40,

The outer race of bearing 48 is secured within the spindle body 36 while the outer race of bearing 44 is located within the motor housing 44. The outer race of bearing 46 is located at the interface between the spindle body 36 and the motor housing 38, and also forms the location reference between the two.

During manufacture two of the bearings are first aligned, and then the third bearing is adjusted radially so as to accurately align with the other two bearings, so that the shaft 27 runs true.

To facilitate a comparison of Figs 3 and 4 the spindle and motor housings 36, 38 are shown in dotted outline in Fig 4

More detail of the motor is shown in Fig 5 which shows the shaft 27, rotor 40, stator 50 and housing 38. Around the stator is a cylindrical coolant jacket 52 through which cooling liquid (typically water) is caused to flow from an inlet 54 to an outlet 56. In so doing it is forced to traverse a helical path denoted in dotted outline at 58, so that there is no short straight path between inlet and outlet. In this way heat is removed in a generally uniform manner from the stator 50 and the housing 38 and no one region of the housing or stator should become hotter than any other region thereof.

Fig 6 shows how an oil collection chamber 60 can be fitted below a hydrostatic bearing housing 62 so as to collect oil under gravity as it leaves the bearing. By incorporating a seal 64 composed of poor thermal material between the chamber 60 and the housing 62, to

form a thermal break, so any heat contained in the oil will not heat up the lower part of the housing 62 relative to the upper part thereof, as could otherwise happen, resulting in possible distortion of the housing 62. Oil leaves the chamber 60 via passage 66 to return to a reservoir (not shown) which may include an oil cooler.

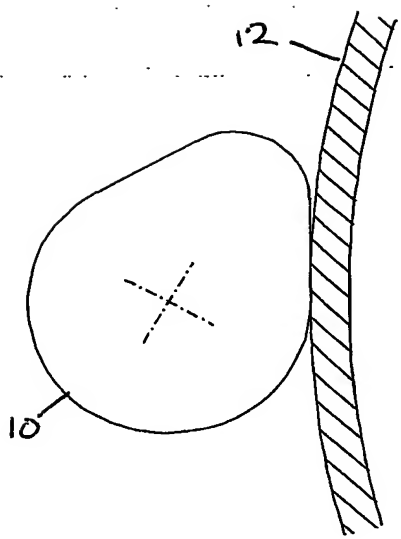


Fig 1(a)

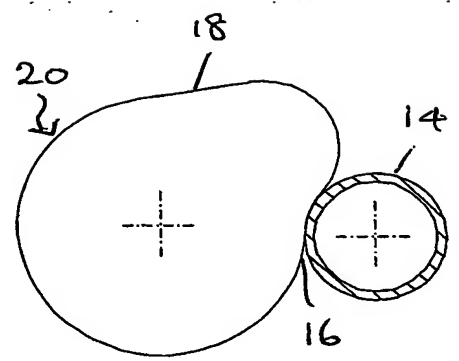
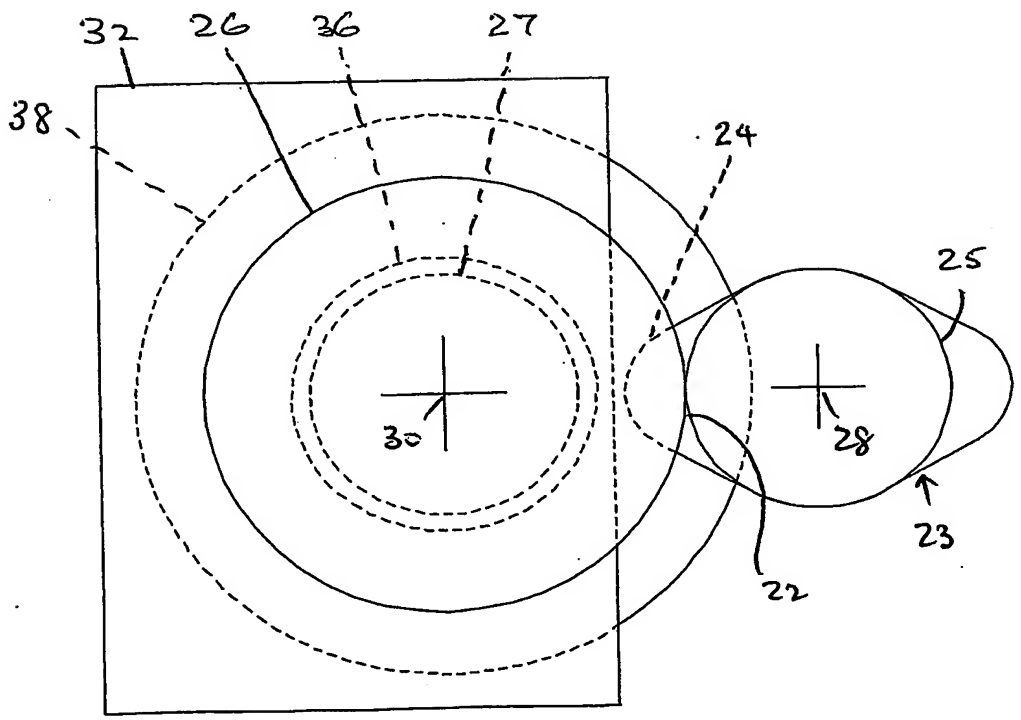


Fig 1(b)

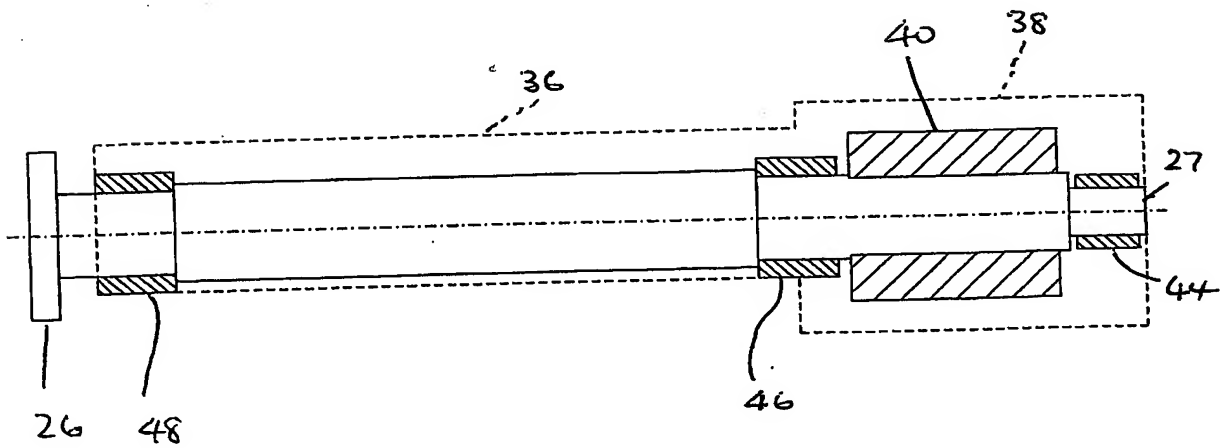
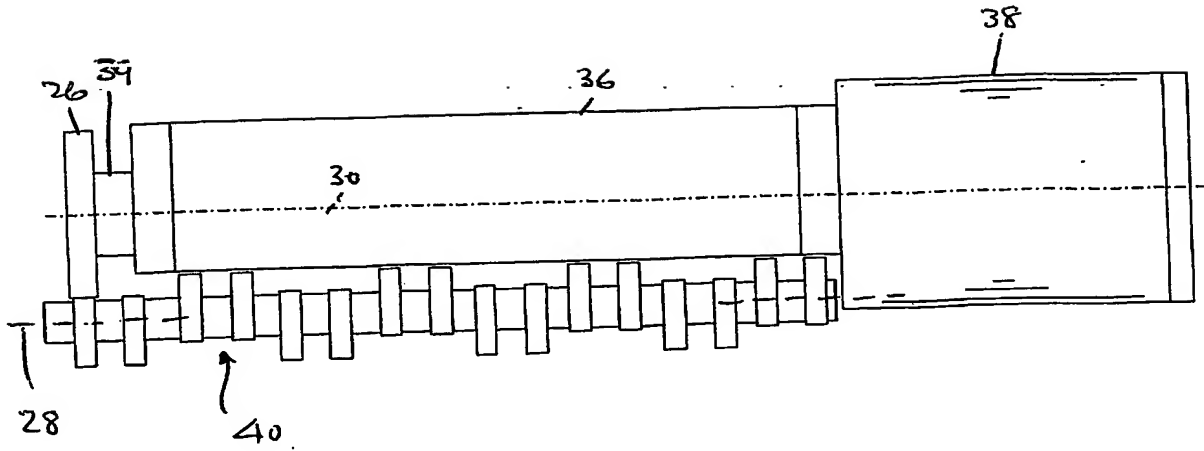


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Fig 2

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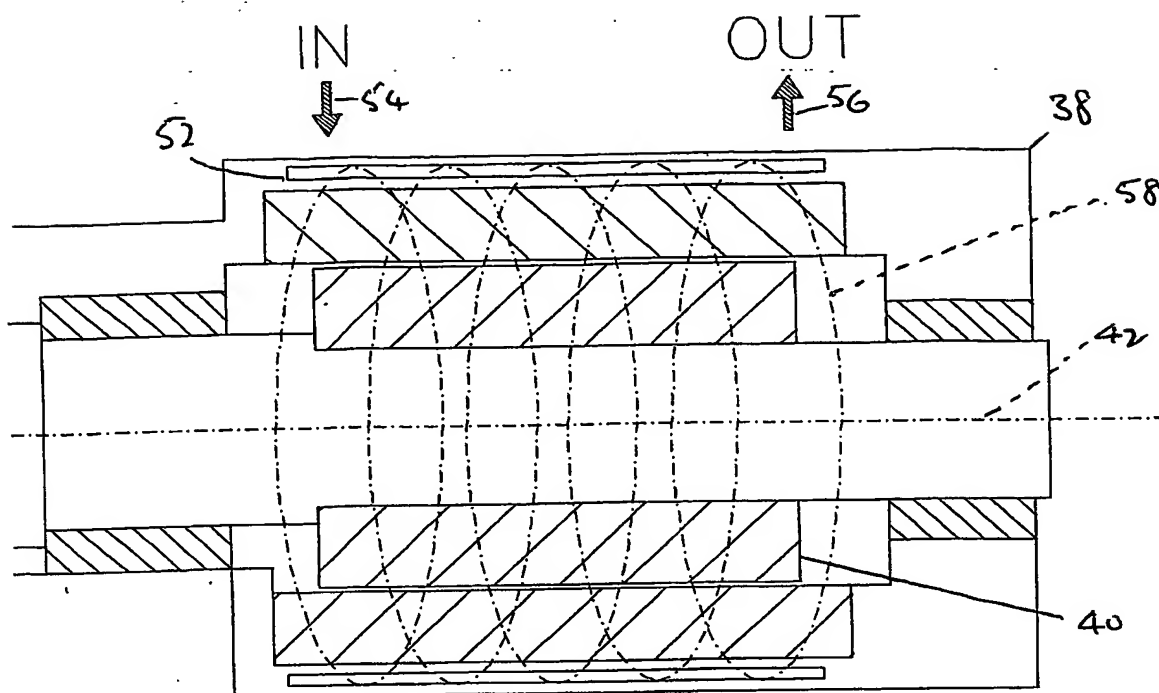


Fig 5

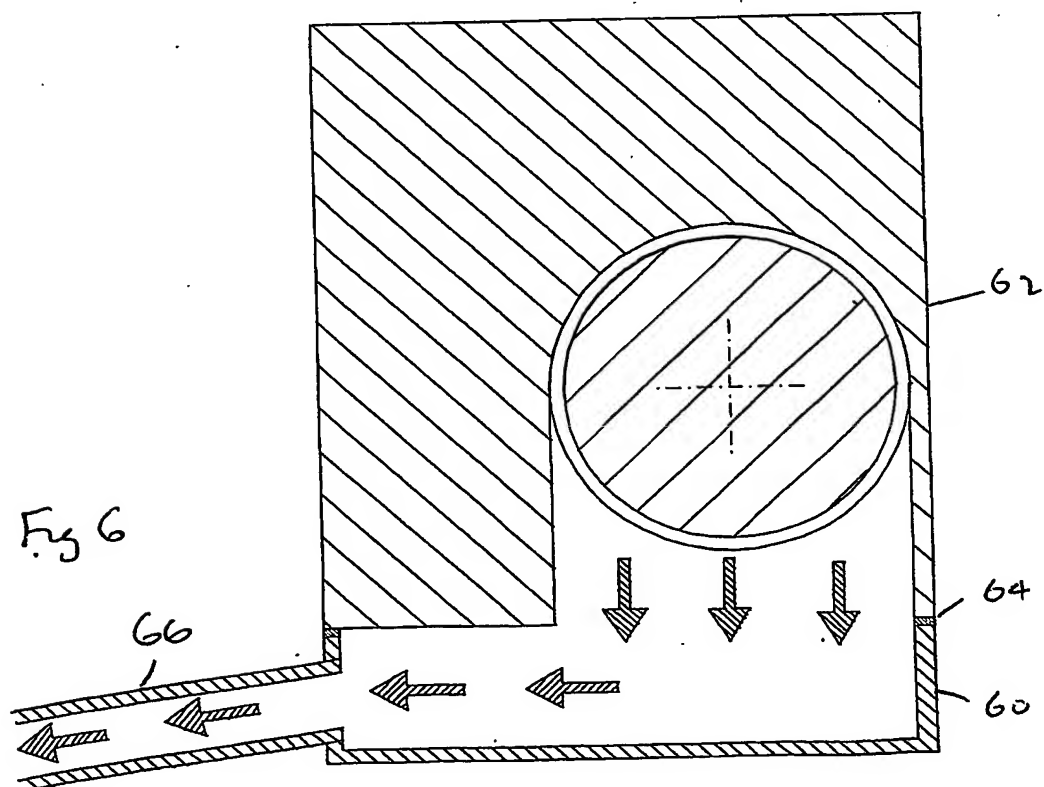


Fig 6

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